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# Simulation Tools for Evaluating the Operational Performance of the Mobile Offshore Base


## Abstract

The goal of the Mobile Offshore Base (MOB) Science and Technology Program undertaken by the Office of Naval Research (ONR), was to establish the feasibility and cost of a MOB. As part of the ONR program, a suite of performance evaluation modeling and simulation tools were developed. The purpose of these tools is to provide an objective and consistent method for evaluating the operational capability of different MOB concepts. The models developed include an operational availability model for evaluating the overall functional performance of different concepts, a family of cargo transfer rate models for estimating open-ocean cargo transfer at a MOB, and an air cargo transfer rate model. While not directly related to logistics performance, another family of models was developed for the evaluation of construction feasibility for all of the MOB concepts developed to date under the ONR program. This model addresses some logistics issues related to construction of a large offshore facility. This paper briefly describes the function, logic and output from these models. With moderate enhancement, these models, or portions of them, could have direct applicability to wider logistics application including the evaluation of logistics operations from one or more vessels in a seabase.


## Introduction

In concept, a Mobile Offshore Base (MOB) is a modular floating base that can be deployed to an area of national defense interest to provide flight, maintenance, supply and other forward logistics support operations for U.S. and Allied forces. MOB modules will most likely be semisubmersibles, which have significantly smaller wave-induced motions compared to conventional hulls. This modularity will support the widest possible range of air support, ranging from vertical/short takeoff and landing (VSTOL) aircraft using a single module to conventional takeoff and landing (CTOL) aircraft using several serially aligned modules approaching 6,000 feet in length. In addition, a MOB would accept ship-borne cargo, provide nominally 3 million square feet for equipment storage and maintenance, store 10 million gallons of fuel, house up to 3,000 troops (an Army heavy brigade), and discharge resources to the shore via a variety of landing craft.

In FY96, the Office of Naval Research (ONR) assumed leadership of a Science and Technology (S&T) Program to advance critical design technologies for MOB, and to establish feasibility and cost . There are no historical precedents for designing and building floating platforms as large or as multifunctional as MOB. This government-sponsored S&T program is focusing on the feasibility of long, interconnected, open-ocean floating platforms. The program will critically examine and advance existing commercial design standards to provide the classification societies and offshore industry with the capability to confidently design and build MOB platforms with an acceptable level of risk. ONR is presently investigating whether a MOB represents credible operational capability for Naval and Marine Forces.

### SYSTEM CONCEPTS

Four designer/builder/operators from the offshore industry were contracted to develop MOB “point” designs using semisubmersible modules. The key difference among concepts is the method of connection.

*Non-Linear Compliant Connector Concept*: The concept proposed by McDermott Engineering features five, 300-meter-long, steel semisubmersibles, connected at the deckhouse level to form a 1500-meter-long runway. The arrangement is shown in Figure 1. Module connection is made with a centerline ball joint, combined with preloaded, nonlinear, compliant connectors (port and starboard).

**FIGURE 1. Non-linear Compliant Connector Concept. Assembled 5 module MOB (top). Single Base Unit (SBU) module (bottom)**

<u>*Independent Semi-submersible MOB Concept:*</u> This concept proposed by Bechtel National Inc. eliminates inter-module connectors entirely and depends upon active Dynamic Positioning to keep the steel semisubmersibles in close alignment (Figure 2). Light, limited-width, flexible bridges are used to span the gaps between the three 488-meter-long modules and to create the runway, but these bridges do not provide any structural connection between the modules.

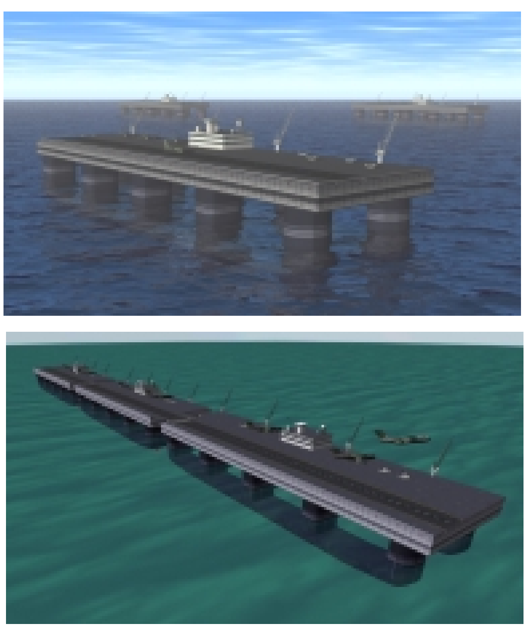

**FIGURE 2. Independent Semi Submersible Concept**

<u>*Hybrid Steel/Concrete Hull Concept*</u>: The Aker concept consists of four 380-meter-long semisubmersibles connected at the deck level using elastomeric connectors. The center connector resists longitudinal and lateral relative motions, and the port and starboard connectors resist vertical motions (therefore, relative roll). This design features a steel deck structure mounted on a post-tensioned concrete semisubmersible hull (Figure 3).

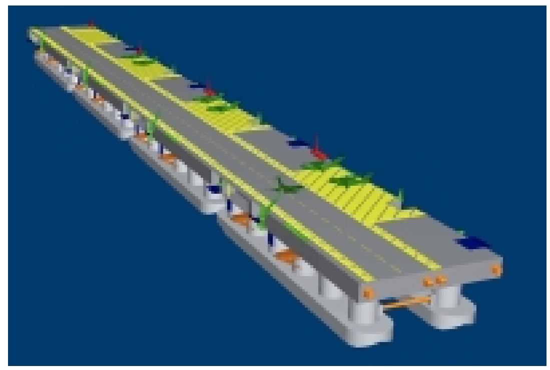

**FIGURE 3. Hybrid Steel/Concrete Concept**

<u>*Flexible Bridge Concept:*</u> The concept developed by the Seabase consortium of Kvaerner Maritime (Norway) and Boeing features three 258-meter-long, steel semisubmersibles, connected by 430-meter-long, flexible bridges to form a 1,500-meter runway (Figure 4). The flexible bridges are rigidly connected to the semisubmersibles, but flex between the connectors to provide smooth gradual deflections in the runway.

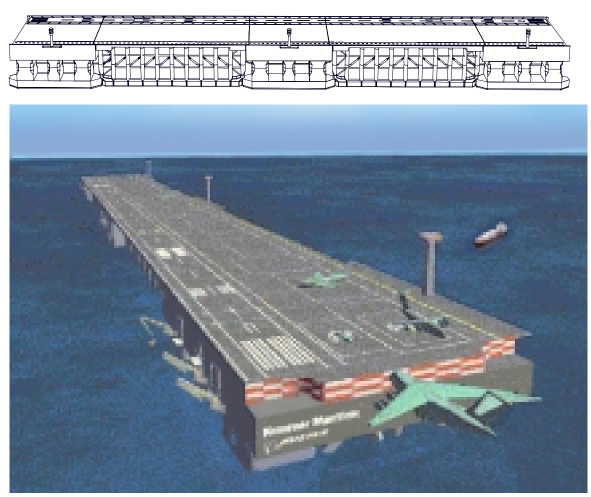

**FIGURE 4. Flexible Bridge Concept**.

**TABLE 1: Major Characteristics of MOB Concepts**

| Concept: | Hinged | Independent Module | Steel & Concrete | Flexible Bridge |
|---|---|---|---|---|
| Developer: | McDermott | Bechtel | Aker | Kvaerner |
| Module Length (m) | 300 | 488 | 380 | 258 (Semi)<br>430 (Bridge) |
| Module Width (m) | 152 | 120 | 152 | 171 |
| Displ./Module (LT) | 258,720 | 413,105 | 586,693 | 207,000 |
| Payload/Module (LT) | 63,446 | 98,214 | 91,339 | (data not avail.) |
| Storage Volume/Module (cu. ft.) | 22,600,000 | 42,000,000 | 31,750,000 | 11,275,500 |
| Number of Modules in Full System | 5 | 3 | 4 | 3 Semi's<br>2 Bridges |
| Total System Length (m) | 1500 | 1555 | 1525 | 1500 |
| Draft (m) | 39 | 35 | 36.5 | 42 |

Because the preliminary Mission Needs Statement was not explicit about troop numbers, cargo tonnage, transit speed, and certain other design criteria, there are substantial differences in platform characteristics. Table 1 shows the major characteristics of each of these concepts.

## Performance Based Simulation Tool Development

It became apparent as the various concept designs began to develop that the differences in size and mass of the structures would make their response to environmental loads quite different. There was also a substantial difference in the volume and payload capability of some of the concepts, raising questions about the ability of each of these designs to meet the required Mission Objectives.

To address this difference in performance characteristics of the various proposed concepts, a family of performance based simulation tools were developed to allow an objective and consistent comparison of sometimes radically different and complex structures. Some of these simulation models offer the ability to conduct reverse engineering analysis to help establish requirements in cases where they could not be directly derived from the MNS (i.e., a number of cargo transfer cranes, aircraft loading spots, fuel storage requirement, etc.). These simulation tools also provide a capability to conduct parametric and sensitivity analyses allowing the design engineer to determine the effect of changing various characteristics of the design on the overall performance of the concept. They also allow mission planners to quickly determine the effect of altering mission requirements on the overall performance and cost of a MOB.

### SIMULATION TOOLS DEVELOPED FOR PERFORMANCE AND CONSTRUCTABILITY EVALUATION

The ONR MOB Program has emphasized objective, probability-based measures of performance, cost, and risk. When used properly, these tools can identify design bottlenecks, compare concepts, and quantify the impact of changes in mission requirements. Four performance based simulation tools have been developed under this program to date. They are:

*Operational Availability Model.* This model statistically estimates the percentage of time the MOB can perform a given mission. The model considers the probabilistic failure rate of key systems or components, the percentage of time lost to bad weather at any designated location throughout the world, and other factors that affect mission performance. This model provides a unique integration of classical probabilistic operational availability modeling of electrical, mechanical and structural reliability with actual historical meteorological and oceanographic environmental data.

*Ship Cargo Transfer Rate Model.* A discrete-event simulation model was developed to evaluate the at-sea transfer rates of containerized and rolling cargo between the MOB, sealift ships, and lighters. Key factors included cargo handling equipment characteristics and relative motions between the floating entities. The results from this model can be transferred directly to the operational availability model.

*Air Cargo Transfer Rate Model*. A series of discrete-event simulation models were constructed by NFESC to evaluate the influence that airfield layouts had on the number of aircraft that could be handled by a MOB during a discrete period of time.

*Construction Feasibility Assessment.* To assess the feasibility of MOB hull construction, a family of models was developed to evaluate the risks and costs of different construction strategies for different MOB concepts. Five design concepts were modeled for two construction scenarios, and cost estimates were developed for construction of the hull. These modes address some logistics issues related to MOB construction.

### SOFTWARE PLATFORMS AND MODEL TYPES

All of the models described in this paper were developed using either Extend simulation software by ImagineThat Inc. or ARENA simulation software by Systems Modeling, Inc. ARENA was used as the platform for the sea cargo transfer rates models; all other models were based on Extend. Extend is an easy to use, general-purpose simulation software package capable of both discrete-event and continuous simulation. Extend is graphically oriented, and both displays and organizes modeled elements into hierarchical "blocks", and provides simple animation features showing the progress of the simulation. ARENA is a more sophisticated discrete-event simulation software program with the capability to include detailed representative animation of the processes modeled.

Discrete-event simulation is based on the occurrence of events of a process, regardless of time. The simulation time is advanced to the time corresponding to each event as it occurs, rather than tracking changes at a fixed time interval. This type of model is best suited for modeling processes like the assembly of parts in a manufacturing process. Events modeled would include the arrival of raw materials, the fabrication of parts, the assembly of subsystems and final assembly. This type of simulation provided the best fit for the ship cargo transfer rate models, the air cargo transfer rate model, and the construction models described in this paper.

In continuous simulation, time is advanced at a fixed time step. Continuous modeling is most often used to simulate processes where values change directly as a function of time, such as chemical reactions or other physical processes like fluid flow. Because this type of modeling must check the state of the processes at each time step, whether or not a change has occurred, it is usually slower than discrete-event simulation. However, continuous simulation was selected for development of the operational availability model, as it is more intuitive and hence easier to use in the development of a model for simulating the complex operations and systems of a MOB.

## Operational Availability Model

In order to meet the ONR MOB S&T Program goal of determining technical feasibility of a MOB, the capability to perform an objective evaluation of a given concept in a representative operating environment was needed. To this end, Bechtel National Inc. was tasked with the development of a simulation-based operational availability model capable of evaluating the functional performance of different MOB concepts at particular sites, given mission-derived performance criteria. This development effort also helps satisfy the Navy policy that "…Ao shall be the primary measure of material readiness for weapon systems and equipment" (Chief of Naval Operations, 1987).

The model, dubbed the MOB Performance Assessment Tool (MPAT), is believed to be the first use of a physics-based reliability model and simulation tool using actual metocean inputs. The model is a time-domain simulation model developed using Extend. The model addresses MOB performance on the basis of mechanical and structural reliability of the platform and its subsystems, but unlike traditional reliability models, also evaluates performance parameters against environmental effects and mission requirements. For example, the model addresses the impact of weather and seastate on platform motions, air operations and sea cargo transfer (among other operations), tracks fuel use over the duration of the mission, accounts for the probability of refueling in the given weather conditions, and tracks the amount of cargo transferred and air sorties completed to meet mission requirements. This is in addition to the standard reliability calculations for the systems involved. The model is capable of simulating different designs and configurations for the MOB as well as different complex missions and accounts for performance during transit of modules. The model includes an environmental database, providing access to 23 years of hindcast environmental data at 22 sites worldwide. The model enables the evaluation of the performance of a given MOB configuration in a particular mission, as well as allowing statistical analysis of performance using the multiple years of environmental data.

## OVERVIEW OF MODEL

MPAT was developed to model three general categories of performance: mechanical and structural reliability for a given concept, the ability to conduct specific operations such as air operations or cargo transfer operations at sea, and the ability to meet the goals of a specific mission. These three categories build upon one another as shown in Figure 5. The basic hardware capability is needed to perform any distinct operations, and operational capabilities are needed to conduct any mission.

While not graphically represented in the same manner as Figure 5, these three predominant divisions of the MPAT are included in its opening screen in Figure 6, showing the top level structure of the model.

The basic hardware configuration and properties for a MOB concept are input by the user in the MOB Configuration and MOB Hardware and Behavior Properties Blocks and verified by the Check MOB Block of the model shown in Figure 6. The model was developed to be

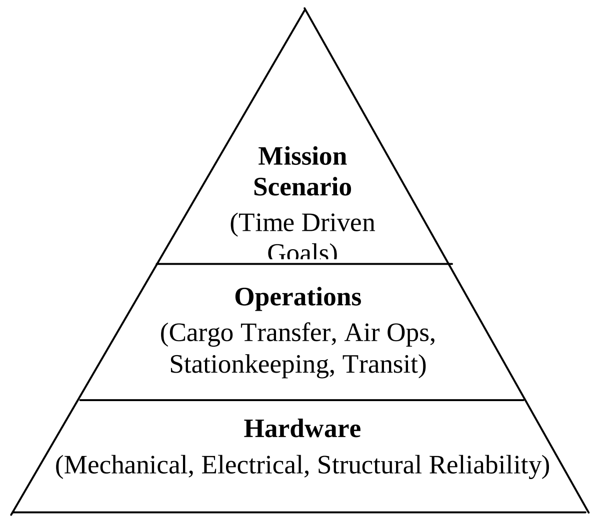


**FIGURE 5. Basic Performance Categories Modeled by MPAT**

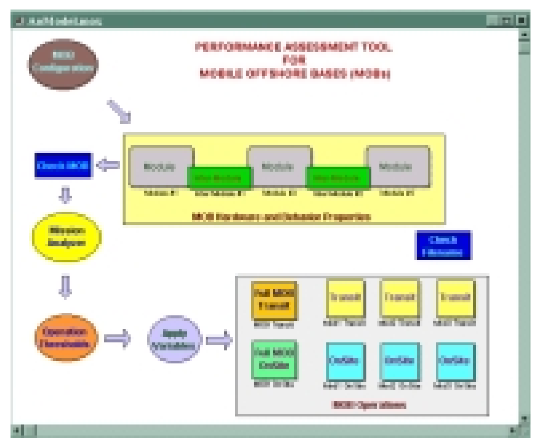


**FIGURE 6. Top-Level Structure of MPAT Model (After Bechtel National Inc., Dec 1999)**

generic enough that a wide range of MOB concepts could be evaluated using the model, including all concepts developed to date under the MOB S&T Program. In this portion of the model, the user sets the basic configuration for the MOB (the number of modules, the presence of connectors, the reliability properties for the MOB's mechanical and electrical systems, and the transfer functions or response amplitude operators (RAO's) for weather-related effects, such as module motions and connector loads. The user is permitted to apply the same values to all modules, or to enter different values for different modules. Once the basic configuration is established in the MOB Configuration Block, the MOB Hardware and Properties Block displays the correct number of modules and connectors. The example shown in Figure 6 shows a three-module system that uses connectors. The user can click on each of these components in the Hardware and Properties Block to enter properties specific to that particular component. Clicking a block leads the user to progressively more detailed levels of the system. For example, within the module block is a station keeping system block, containing lower level blocks for the electric plant, sensor system, control system, thruster system, and fuel monitors. In turn, clicking on the lower-level thruster block, leads the user to a yet more detailed block for describing this system. Reliability data for each component is input using failure and repair times selected from a library of statistical distributions embedded in the model, including normal, lognormal, exponential, Weibull, and uniform distributions. The configuration and hardware portions of this model were based on the Expanded Ship Work breakdown Structure (ESWBS), (Naval Sea Systems Command, 1985), to ensure that all critical subsystems were either directly included in the model, or could be inserted at a later time.

The Mission Analyzer block shown in Figure 6 is where the user specifies the mission profile to be simulated. This includes the location for each module, a time schedule for different operations, including module transit and connection, and mission-based start times and target durations for air operations and sea cargo transfer. Target cargo throughput goals, target air sortie rates, and the type and amount of cargo to be transferred also are input in this section of the model. The model tracks the transfer RO/RO cargo, containerized cargo, pallets, water, fuel, lighterage, aircraft and personnel. The Mission Analyzer Block allows complex operations to be simulated; for example, a mission might include one or two modules onsite, operating independently, later joined by additional modules at which time all modules are connected for some period of the mission. Figure 7 shows such a mission that cold be simulated using MPAT.

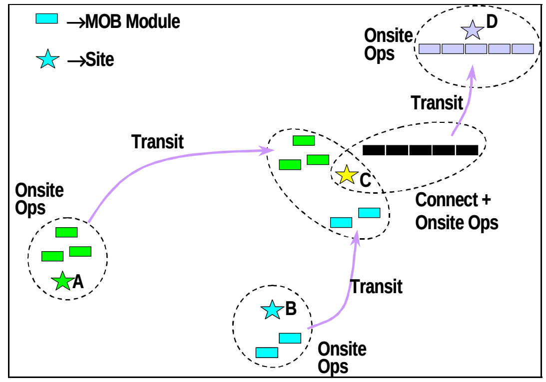


**FIGURE 7. Example Mission Scenario for MOB (After Bechtel National Inc., Dec 1999)**

The Operations Thresholds Block is where the user specifies thresholds for all systems and operations that are affected by weather, including:

- Limiting headwind and crosswind values for different categories of aircraft
- Thresholds for maximum pitch, roll and yaw motions for the modules and inter-module connectors or bridges
- Significant wave height thresholds for different categories of vessels transferring cargo at the MOB
- Connector and structural load limits, including values for recommended disconnection, mandatory disconnection, and permissible reconnection
- Significant wave height limits at which point MOB should be ballasted down to weather severe conditions

The Apply Variables Block shown in Figure 6 gathers and applies all of the input parameters to their appropriate blocks within the MOB Operations Block. That block is the portion of the model that contains all of the programmed logic connecting MOB systems and capabilities.

## WEATHER DATABASE

The weather database contains parameters that describe metocean conditions for every six-hour period from the year 1974 to 1996 at 22 sites around the world, shown in Figure 8. Each six-hour period is treated as a steady-state seastate

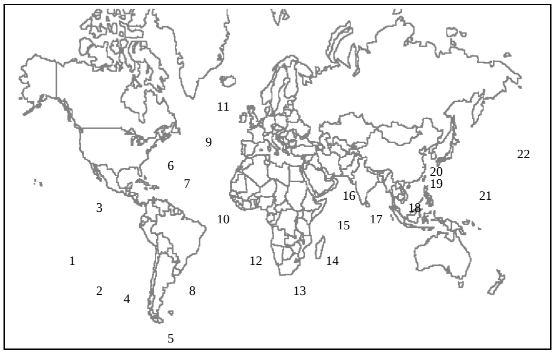


**FIGURE 8: MPAT Weather Data Sites (From Bechtel National Inc., Dec 1999)**

described by wave, wind and current data. Wind and current parameters include average speed and dominant direction. From the wave parameters, a directional wave spectrum is generated and used in the simulation of all weather-related responses. Both wind-generated waves and swell are modeled.

### OUTPUT

Output generated by the model includes operational availability statistics for the MOB as a whole, and for critical subsystems and operations. Output includes the mean and standard deviation of operational availability, mean time between failures, mean time to repair, and the number of "up" and "down" states for each system, subsystem or capability modeled. Probability of mission success, the probability of success for each specific mission task, and mean and standard deviation for start, end and duration of each task is also generated. The model also produces detailed time histories of important parameters such as weather, platform motions, or fuel use. The user can run the model without weather and without a mission profile to generate operational availability statistics for the mechanical systems alone.

### USE AND APPLICATION

MPAT was developed principally for the objective evaluation of different MOB concepts in terms of operational performance, but it also will serve in the following applications:

- Pinpointing those systems where technology and design investment can most impact system reliability and mission performance.
- Conducting cost-benefit studies during design.
- Allocation of reliability requirements during design.
- Mission analysis for determining the impact of operating at different sites, or at different seasons of the year.
- Conducting sensitivity studies to optimize operational plans.
- Identification and quantified prioritization of critical MOB systems and capabilities for a given MOB mission.

Example applications that were run during development of the model to prove the concept included a comparison of availability statistics and cargo throughput rates for different calendar months of operation at a given site, a comparison of fuel demand at different sites, a comparison of stationkeeping loads on different modules, and an analysis of the sensitivity of the seastate threshold for refueling operations on fuel availability.

This model constitutes the most powerful performance evaluation tool developed in the MOB S&T program, and advances the general state-of-practice for reliability and performance modeling to a new level by integrating mechanical reliability, mission simulation, and actual environmental data for the first time. Although MPAT is specific to MOB-type concepts, the basic model structure and logic is transferable to other applications. To this end, application of some of the advances made in this effort, most notably use of the weather database, is currently being proposed to enhance a separate model developed by the Naval Facilities Engineering Service Center (NFESC) for the simulation of cargo from a seabase to troops onshore.

## Ship Cargo Transfer Rate Models

One of the most critical capabilities for MOB is that of transferring cargo to and from vessels alongside. Prospective MOB scenarios include the transfer of cargo to MOB from commercial containerships and Roll-On/Roll-Off (RO/RO) ships, Fast Sealift Ships, Maritime Prepositioning Force (MPF) ships, and other vessels, and transfer from MOB to amphibious ships, lighterage and other craft including the Landing Craft Air Cushioned (LCAC). MOB also could serve as a re-supply point for virtually any other vessel in the fleet. Current in-stream offloading operations, such as those used during Joint Logistics Over the Shore (JLOTS) operations, are curtailed by environmental forces creating relative motion problems between vessels, load pendulation problems, and exceeding lighter capability. These same problems exist for transfer to and from a MOB, with the added complications of open-ocean conditions, and potentially greater throughput rate requirements. While experience with in-stream offload operations has shown a drop-off in productivity with increasing seastate, and relative motions and pendulation have been pinpointed as the obstacles, no method for predicting cargo transfer rates between vessels has been developed that accounts for each step in the cargo transfer process. Instead, it has generally been assumed that when relative motions or wind speeds reach a threshold, cargo transfer can no longer occur. McDermott Technology, Inc. hypothesized that even in degraded environmental conditions there may be windows of opportunity when relative motions would permit cargo transfer to occur, and proposed the development of detailed models of the transfer process to test this theory.

To this end, McDermott Technology, Inc. developed three discrete-event simulation models for the analysis of containerized cargo transfer from a supply vessel to MOB, and of RO/RO cargo transfer both to and from the MOB. The models consider the motions of the MOB and vessel, the characteristics of the cargo transfer system (either crane or RO/RO ramp properties), and the design and cargo load of the vessel alongside. The models can be used to estimate cargo transfer rates as a function of vessel design, crane or RO/RO ramp design, wave environment, and heading. The models also can be used to support design trade-off studies, by helping to identify weaknesses in the design and targets for the most cost-effective improvements. All three models were developed in the same general format, using ARENA simulation software. The general format adopted by the developers allows different cargo handling systems and vessels to be evaluated easily. While the models currently are limited to simulating the transfer of cargo between MOB and vessels alongside, this general format also should allow the models to handle other in-stream offload cases with only moderate changes to the models.

In addition to providing valuable insight specific to the cargo transfer process, results from these models can be used in the operational availability model MPAT, described above, to more accurately reflect cargo transfer operations between the MOB and vessels alongside in an overall operational assessment using MPAT.

## GENERAL MODEL STRUCTURE AND LOGIC

All three cargo transfer rate models have the same basic structure illustrated in Figure 9. Four separate input files contain data regarding the geometry of the vessel alongside the MOB, information on the cargo load being carried by the vessel, motion data for both the vessel and the MOB, and data on the crane or RO/RO ramp used to transfer the cargo between platforms. For the RO/RO transfer models, the vessel, cargo and transfer mechanism data are all combined into one input file, as much less input data information is required compared to the container model. All input files are in Lotus ".wk1" format.

The motion data file for all models contains translational and rotational data for all six degrees of freedom, for both the vessel and the MOB, at each second in time to be simulated. Generation of this data is separate from the transfer models, and should account for the interaction between the platforms and their mooring mechanism. Several hours of data are required to provide valid statistical output from the model.

The other input files contain information on the geometry of the cargo vessel, the configuration of the load, and transfer mechanism parameters

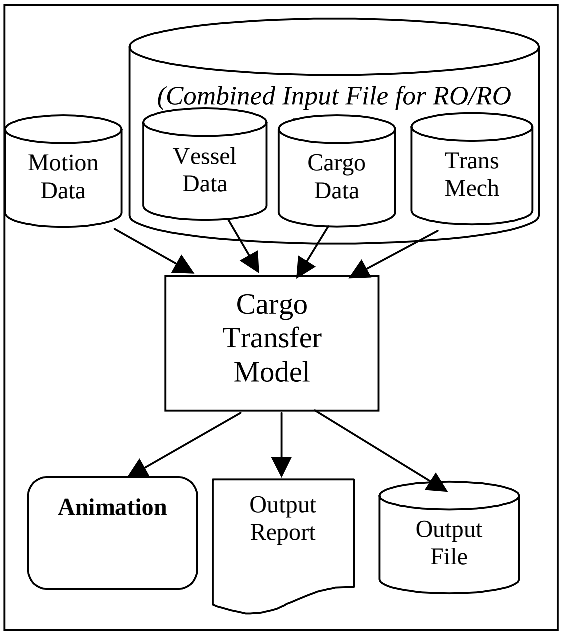

**FIGURE 9. Structure of Cargo Transfer Models (After McDermott Technology, Inc., 1999)**

and limits. More information on these input data will be provided in the sections of this paper addressing the specifics of the two types of models.

For all models, the basic logic is the same. All steps in the cargo transfer process are broken down into discrete steps. For the container model, these include lifting the crane hook to the traveling position, moving it over the target container, focussing on the target container, etc. For the RO/RO model, they include moving a driver or tractor from the MOB to the vessel, acquiring a vehicle, moving it to the top of the vessel ramp, moving it down the RO/RO ramp, etc. The time required to complete each step is either provided in the input file for the transfer mechanism, or is calculated using rate information from the input file and distance traveled by either the crane or vehicle. As the model progresses through each step of the transfer process, the motion data file is checked to determine what the relative motions of the two platforms are for each second of time in that step. If the motions ever exceed the limits imposed by the cargo transfer mechanism input data, the model resets that step to its start point, and reiterates this process until acceptable motions are reached in the motion data file that allow that step to be completed. The model keeps track of the time and nature of all instances that limiting values are exceeded, so that a statistical analysis of the results can be used to identify the root causes limiting cargo transfer. This process continues until all cargo identified in the input file is transferred.

As the model is running, an animation screen showing the movement of either containers or vehicles is displayed. The animation also shows indicators of relative motions and tallies of cargo items successful transferred and those remaining, simulation time, cumulative delay time, average cycle time per transfer, and whether or not the simulation is currently experiencing a motion-induced delay. Examples of the two animation screens are provided in the following sections that describe the specifics of the two types of models.

A standard output report is generated by ARENA for each model, showing minimum, maximum and average values for specific steps in the process, a summary of delays encountered during the simulation including the number of delays and the cumulative duration of the delay for each type of delay, the average transfer rate for the entire simulation, the total number of cargo pieces moved, and the length of time simulated. A separate output file also is generated that contains a record for every second that a delay is calculated. The file includes information on the cause of the delay, the value of relative motion triggering the delay, and for the container model, identification of which container location was affected. Although no other output files are included at this time, files for any output variable of interest can easily be added using ARENA's Output Processor.

## CONTAINER TRANSFER MODEL

Four separate input files are required for the container transfer model: the motion data file described earlier, and vessel data, cargo data and crane data files. The vessel data file contains the position of the center of gravity of the vessel in relation to the center of gravity of the MOB module, and position data for each container cell or above-deck location relative to the center of gravity of the vessel. The file also contains a value for the time required to store each container on the MOB once it has been released to the MOB cargo deck by the crane. The cargo data file contains position information on each container to be offloaded, listed in the order of offload. Data on hatches that must be removed during the offload also are included in this file. The crane data file contains twenty-one parameters that describe the operation of the crane being used, including travel rates for each translational motion (x, y and z), the amount of time required to perform specific tasks (e.g., insert the spreader bar in a cell guide, latch onto a container, etc.), and limiting values for operation that may be impacted by relative motions. The following five "delay gates" limit cargo transfer operations:

- Angle of vessel (in roll or pitch) at which the operation of focussing on the target container is delayed.
- Angle of vessel (in roll or pitch) at which the operation of lowering a spreader bar into a cell guide is delayed.
- Angle of vessel (in roll or pitch) at which the operation of lifting a container out of a cell guide is delayed.
- Relative velocity (in x, y or z direction) at which the operation of focussing on the target container is delayed.
- Relative velocity (in x, y, or z direction) at which the operator would wait until the wave peak arrives to lift a container from a cell guide. (This prevents the container below in the cell from impacting the lifted container if the upward velocity of the vessel is greater than the velocity of the container being lifted by the crane.)

The container model input file was based on the use of the National Institute of Standards and Technology (NIST) Robo-Crane. To simulate the Robo-crane's automated operational features, as well as those of less sophisticated systems, a range of different automation possibilities is accommodated in the input file. The user enters a code corresponding to the type of motion compensation system the crane has, and also enters the appropriate time for focus-on-target operations corresponding to the system to be modeled. The user also enters a percentage value corresponding to a projected latch failure rate, and the time required to correct a latch failure.

The container model simulates the following step-by-step process for moving containers from a vessel to the MOB:

1. Lift crane hook to travel position.
2. Move to target.
3. Focus on target.
4. Insert in cell guide.
5. Lower in cell guide.
6. Latch onto container.
7. Lift in cell guide.
8. Lift to travel position.
9. Move to unload location.
10. Lower to unload location.
11. Unlatch container.
12. Store container on MOB.

Once step 11 (unlatch container) has been completed, the crane is free to start again at step 1 to offload the next container. Step 12, storing the container on the MOB, can occur independently of crane operations once the container has been unlatched. During each of the crane-dependent steps, the relative motion between the top of the container being unloaded and the hook of the crane is calculated from the motion input file data, and the values are checked against the delay gates. An example animation screen for the container transfer model is shown in Figure 10.

This model can be used for estimating the cargo transfer rate between vessels and the MOB at different seastates and headings, and to identify those process steps and equipment parameters that are most likely to cause delays. This type of information can be used to focus technology advancement efforts for logistics operations, and to evaluate different operational scenarios and technology concepts.

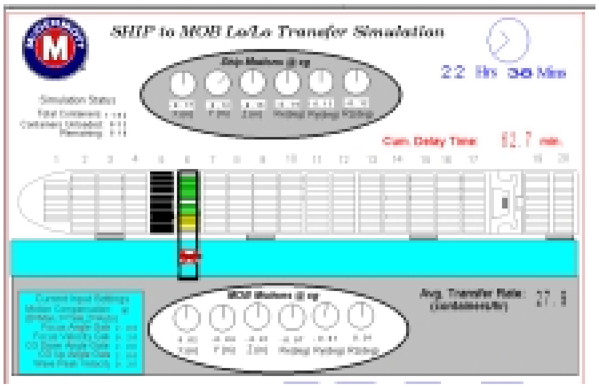


**FIGURE 10. Animation Screen, Container Model (After McDermott Technology, Inc., 2000)**

## RO/RO TRANSFER MODELS

The two RO/RO transfer models are basically the same, with one simulating transfer from the vessel to MOB, and the other from MOB to vessel. Both models simulate the transfer of rolling stock, designated as some combination of self-powered vehicles and those requiring a tractor-trailer, using a one-way vessel ramp. For both RO/RO models, the input file requirements are substantially lower than for the container model, and all input data other than motion data is contained in a single input file. This file contains the location of the vessel's center of gravity relative to the center of gravity of the MOB module, the number of self-powered and tractor-pulled vehicles to be offloaded, the number of drivers and tractor-trailers available, travel speed for each type of vehicle at different legs of the transit path, the average time to retrieve and store the vehicles, and the length of the ship's RO/RO ramp. Two delay gates are set using the input file: the maximum angle of the vessel's RO/RO ramp for transit operations, and the pitch angle of the vessel at which transit operations cannot be performed. The file also allows the user to set the relative priority for each of three types of traffic using the vessel ramp: self-propelled vehicles and loaded tractor-trailers leaving the vessel, and empty tractor-trailers going back to the vessel to retrieve a load.

The RO/RO models simulate the following step-by-step process for moving containers from a vessel to the MOB (or vice versa):

1. Drivers for self-propelled vehicles transit from MOB to vessel over gangway.
2. Tractor-trailers move from MOB to vessel using vessel RO/RO ramp (this step is simultaneous with step 1).
3. Drivers or tractor-trailer retrieves vehicle from vessel hold.
4. Vehicle is moved to queue at top of vessel RO/RO ramp.
5. Vehicle proceeds down ramp onto MOB landing platform.
6. Vehicle moves up MOB ramp.
7. Vehicle is stored on MOB and driver or tractor is returned to main deck for transfer to vessel.

Once step 7 (vehicle stored, driver back on MOB deck) has been completed, the driver is free to start again at step 1 to retrieve the next vehicle. The only motion-dependent steps in this model are 2 and 7, where traffic is actually on the vessel's RO/RO ramp. During these steps, the model compares relative motion between a point at the top of the vessel's ramp and one directly below it at mean water level to the limiting delay gate values to determine if transit is allowed. An example animation screen from the RO/RO model for transfer from a vessel to MOB is shown in Figure 11.

This model can be used for estimating the rolling cargo transfer rate between vessels and the MOB at different seastates and headings, and to evaluate different equipment and operation parameters, such as ramp length, the number of available drivers, and distance to storage locations on the MOB.

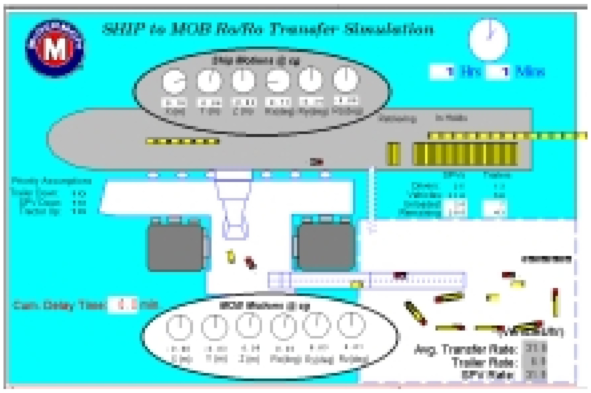


**FIGURE 11. Animation Screen, RO/RO Model (After McDermott Technology, Inc., 2000)**

## RECOMMENDATIONS FOR ENHANCEMENT AND APPLICABILITY TO WIDER LOGISTICS APPLICATIONS

In order to more accurately model all critical impacts to open-ocean transfer of cargo, and to make the models applicable to a wider range of in-stream cargo transfer operations, the following recommendations have been identified for enhancing and expanding the models' capabilities:

- Modify all models to facilitate the simulation of seabase platforms (other than MOB modules), by specifying necessary characteristics in an input file.
- Expand the container transfer model to account for the impact of wind and wind gusts on load pendulation. The current model does not address wind as it was assumed that the sophisticated developmental crane modeled would adequately compensate for all wind-related effects.
- In all models, convert the gate logic to include motion prediction to better replicate realistic operations.
- Expand the container transfer model to simulate a variety of crane types.
- Collect empirical data from dockside operations as well as in-stream offloading operations to generate representative input data.
- Expand the container transfer model to allow multiple cranes.
- Combine the container and RO/RO transfer models to allow simulation of offloading multi-purpose vessels such as MPF ships.
- Expand the RO/RO transfer model to allow simultaneous offload from two ramps to accommodate the Large, Medium Speed RO/RO's (LMSR) capabilities.
- Model the manual focus step in the container transfer model as a probability distribution.
- Modify the container transfer model to include the time required to warp the vessel, if needed in prospective operational scenarios.
- Verify and validate all models.
- Develop a library of representative vessel deck views for the animation.

## Air Cargo Transfer Rate Model

A study of air operations requirements (Naval Air Warfare Center, 1999) identified several possible air field layout configurations for a MOB. The configuration variations ranged from a single runway/taxiway air field that required a MOB with a minimum deck width of 100 meters to a 190 meter wide MOB with separate runway and taxiway. This two-fold range in width of the MOB flight deck would have a significant effect on the operational performance in extreme weather conditions and cost of construction. Selection of the air field layout and therefore the required flight deck width will depend on the number of aircraft sorties (take-off's and landings) that are needed to meet mission operational requirements.

To obtain a better understanding of the affect of MOB width on aircraft sortie rates, a series of simulation models were constructed. The Extend simulation modeling software was used to create the discrete-event models used to evaluate the influence that airfield layout had on the number of aircraft that could be handled by a MOB during a discrete period of time.

The basic model was developed by first identifying the primary air and ground operations involved in transferring cargo and personnel from a MOB to a Small Austere Airfield (SAAF). Discrete-event modeling blocks were selected that represented these functions. The functional blocks were then connected using flow control blocks that limited the number of items that could enter or exit various portions of the model (i.e., the runway) at any one time.

Table 2 identifies the primary functions and features that were incorporated into the initial version of the model.

**TABLE 2. Primary Features and Operations**

| MOB Platform | Off-Platform Features |
|---|---|
| Runway | SAAF - Runway/Taxiway |
| Taxiway | Aircraft unloading area |
| Aircraft Parking - Cargo Transfer | Outbound Flight Path |
| Aircraft Maintenance | Inbound Flight Path |
| Aircraft Refueling | Holding Patterns |

The initial model shown in Figure 11 simulated the narrow (100 m width) MOB with a single combined runway/taxiway. An aircraft that is landing has to touch down, complete its ground roll, turn around and taxi to an available parking space before the runway was available for other operations. The ground operations area of the MOB flight deck was modeled after an analysis of a MOB (Boeing, 1999) with six aircraft parking spaces used for cargo loading/unloading and four aircraft parking spaces designated for maintenance. The SAAF was assumed to be a primitive landing strip with the capability of offloading two aircraft at a time.

The flow control logic applied to the model prevented more than one aircraft from occupying the runway/taxiway at any one time. Aircraft in the holding pattern were not allowed to begin the final approach operation until there was at least one parking space available on the MOB flight deck. The aircraft parking spaces were also gated (controlled access) such that the aircraft had to complete the cargo loading and refueling operation and move onto the runway before another aircraft could occupy the parking

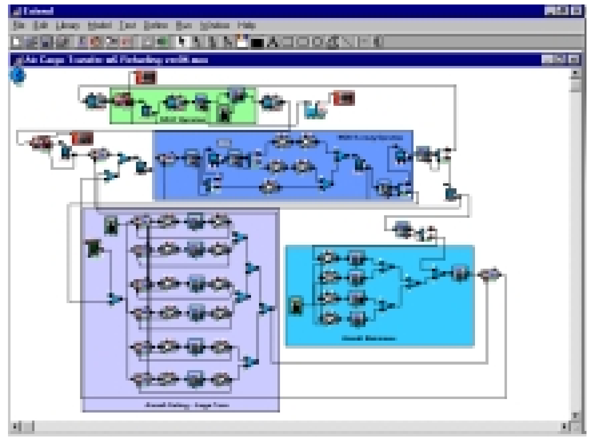

**FIGURE 11. Air Cargo Transfer Rate Model**

space. The model also randomly selects a percentage of the aircraft to undergo maintenance operations while on the MOB. The time required to complete the aircraft maintenance is randomly assigned using an exponential distribution with a mean time of 120 minutes.

The basic flow pattern through the model is as follows:

1. Aircraft arrive in the vicinity of the MOB and enter a holding pattern block.
2. One aircraft at a time lands and taxies to a parking spot where the aircraft is loaded with cargo and refueled. As soon as the aircraft is parked, the runway becomes available for another aircraft to land.
3. Once the refueling operation is complete, the aircraft waits for the runway to become available and then taxies to the down wind end of the runway, turns around, completes the preflight checks and takes off.
4. When the aircraft departs the MOB, it enters a delay block that simulates the flight time to the SAAF.
5. Upon arriving at the SAAF, the aircraft lands, unloads its cargo and takes off again. A queue block simulates a holding pattern that can accumulate aircraft (if necessary) until there is space to land at the SAAF.
6. After departing the SAAF, the aircraft enters a delay block simulating the inbound flight time and then moves into another 'holding pattern' queue in the vicinity of the MOB.

7. The aircraft remains in the holding pattern block until both the runway and a parking space are available at which point it enters the final approach block and the cycle starts over again.

## INITIAL SIMULATION RUNS

During the initial model runs, the number of aircraft available to ferry cargo between the MOB and SAAF was the only variable investigated. The values used in these simulations are shown in Table 3.

**TABLE 3. Initial Simulation Parameters**

| Parameter | Value |
|---|---|
| Runway | 1 |
| Taxiway | 0 |
| Aircraft available for operation | Variable |
| Cargo Loading Stations | 6 |
| Refueling Stations | 6 |
| Maintenance stations | 4 |
| Distance to Objective | 500 NM |
| SAAF Unloading Stations | 2 |

Figure 12 presents the results of four runs where the number of aircraft available for operation were varied from two to fourteen in increments of four. These initial simulation runs revealed that the SAAF became saturated with aircraft offloading cargo as the number of aircraft available for the operation increased passed ten. Additional aircraft began to stack up in the SAAF holding pattern and did not contribute to increasing the cargo transfer rate. The maximum number of sorties achieved was 94 for the 100-hour simulation period. For the conditions assumed for these simulations, an average of about one aircraft per hour could be cycled from the MOB to the SAAF and back. The model blocks accumulate data about the items that pass through the model during the simulation. From these internal accounting data, it was determined that when the flight pattern becomes saturated, the SAAF activity block is utilized 95% of the time while the MOB runway/taxiway is only in use approximately 30% of the time.

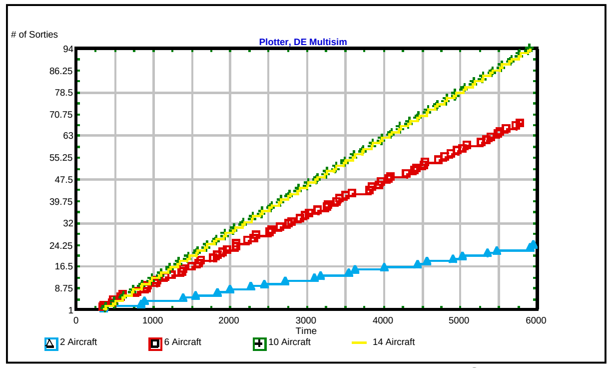


**FIGURE 12. Preliminary Cargo Transfer Rate Data**

## SENSITIVITY ANALYSIS

Following the review of initial simulation runs, a more rigorous series of simulations was conducted with a wider range of parameters varied to investigate their effects on cargo transfer rates. The parameters that were varied during this phase of the study were:

- Number of aircraft that could be unloaded simultaneously at a remote airfield.
- Number of aircraft available for cargo transfer.
- Percentage of aircraft requiring maintenance.
- Distance to objective (which affects refueling time, payload, and flight time).
- Number of cargo loading stations on the MOB.
- Number of aircraft refueling stations.

Figure 13 presents the results of the series of simulations that were run for a range of unloading stations at a remote airfield and a range of available aircraft. In this series, the number of sorties becomes saturated at between 210 and 220 per 100 hours when the number of aircraft available exceeds approximately 20 and more than five aircraft are simultaneously unloaded. Under these conditions, the cargo loading and refueling stations on the MOB became the choke point of the operation.

In the final series of sensitivity analysis runs, the number of cargo loading and refueling stations on the MOB was allowed to vary while the number of available aircraft and remote site

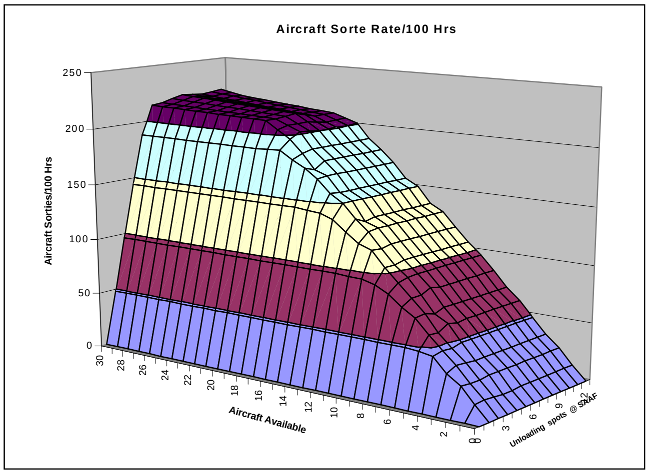


**FIGURE 13. Air Cargo Transfer Rate Parametric Analysis**

cargo unloading stations was set high enough that they did not influence the sortie rate. Under these conditions, the maximum number of sorties converged at approximately 300 (or an average of three aircraft per hour) when the number of cargo loading and refueling stations on the MOB exceeded twelve. Under these conditions, the MOB runway/taxiway became the choke point with the total utilization exceeding 95%. Based on the assumed times for landing, take-off, and taxiing operations, the runway was used 34% of the time for planes taking off, 36% of the time by planes that were landing, and 25% of the time by planes that were taxiing from one location on the MOB to another.

As stated earlier, a major goal of the air cargo transfer modeling effort is to determine the magnitude of the operational benefit from a separate runway and taxiway, for comparison to the negative impacts to seakeeping ability and construction cost associated with the increased width. However, the development of the model simulating the separate runway and taxiway layout has been undertaken only recently and analysis results are not available at this time for comparison with those for the combined runway/taxiway layout described above.

## Constructability Models

As part of the suite of performance evaluation tools developed for the MOB program, the University of Maryland's Center for Technology and Systems Management was tasked with the development of a methodology and simulation models for evaluating the constructability of different concepts for MOB, and applying these tools to a preliminary assessment of MOB concepts developed to date under the ONR program. Because no vessel or offshore structure comparable to MOB has ever been built before, an important facet of evaluating overall feasibility was to determine if the structure could be built, and over what time period, given current and projected U.S. shipbuilding and offshore construction industry capacities. It also was important to the program to identify the risks most likely to impact construction cost and schedule. While not directly related to "traditional" logistics operations, the models are included in this paper as they are part of the family of simulation models developed for the evaluation of MOB concepts, and because the portion of the models that simulates the transportation of components to an offshore assembly site does represent a logistics operation of sorts.

The University of Maryland chose to develop two independent models for each of the five MOB concepts evaluated in their overall study, representing two different construction scenarios for each concept: a terrestrial construction scenario where the final assembly of components takes plan on land, and an afloat scenario where major components are assembled offshore. All models were developed using the Extend software platform, using discrete-event simulation, and have the same basic structure. A simplified representation of the models' structure is shown in Figure 14.

All of the models were based on the assumption that multiple shipyards would produce components contributing to the final assembly of the MOB, so each of the construction-related blocks shown in Figure 14 represents construction of components at multiple facilities. The lowest component levels addressed by the models are fabrication of blocks and panels for the lower and upper hulls, columns, and braces.

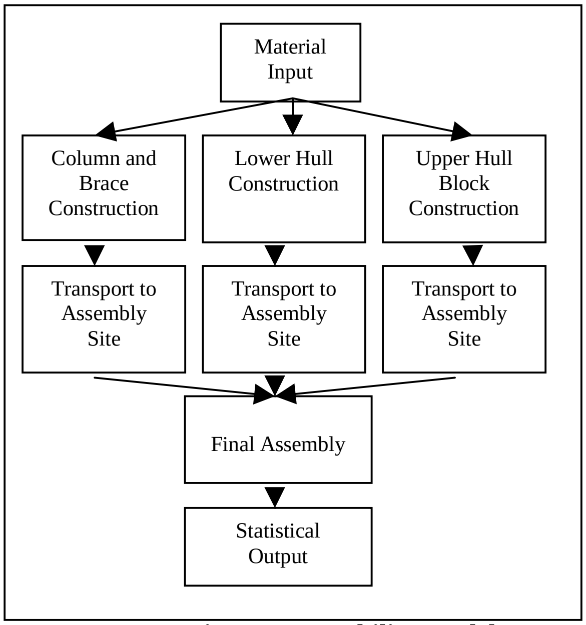


**FIGURE 14. Basic Constructability Model Structure (After Ayyub et al, July 1999)**

All of the models incorporate simulation of the construction sequence for a given concept and construction scenario. This includes the availability of raw materials, the time required for each step in the construction process, the number of shipyards contributing to construction, the transportation of components from individual shipyards to the final assembly site, and final assembly and outfitting. Statistical distributions are used to simulate the variability in these parameters. Because no applicable historical data was available for modeling MOB construction, triangular or beta distributions were used to estimate random duration input for most construction steps. Building, fabrication and erection of components were modeled using a beta distribution, while the assembly and outfitting of MOB modules was simulated by triangular distributions. Gamma distributions were used to model the transportation of components from the fabrication site to the final assembly site.

An innovative part of this model was the inclusion of fuzzy logic sets to address the impact of construction management conditions on cost and schedule of MOB construction. A fuzzy logic inference shell, FUZZLE 3.0, was used to simulate this impact. Two variables of the construction process impacting construction management conditions were included in the simulations: the number of shipyards involved, and the complexity of the construction scenario. Larger number of shipyards and the afloat construction scenario were modeled to have greater negative impact on construction time and schedule than fewer shipyards and the terrestrial scenario.

For the analysis performed using these models, 2000 simulation runs were used to generate the statistics for each concept and scenario modeled. This number of simulations was selected using a ninety-five percent confidence level and a target accuracy of one percent. Construction schedule calculations were based on the critical path of all steps included in the sequence. Construction cost was calculated for the fabrication and assembly of the upper and lower hulls, including columns and braces, but excluding transportation and outfitting costs.
These results fed into a decision analysis process for overall MOB construction that considered cost, schedule, concept length, the impact of labor and safety, and environmental impact. The overall results of the study concluded that construction of a MOB was feasible using the projected capabilities of the U.S. shipbuilding and offshore construction industry. These models can be used in future studies for MOB to determine the impacts of different construction scenarios, and the sensitivity to changes in input parameters such as the number of shipyards used, the availability of materials, the cost of labor, or the length of MOB to be constructed.

In a follow-on study, the University of Maryland expanded the afloat construction simulation model for one concept to better simulate the effects of weather on the transportation, assembly and outfitting stages of construction. The expanded model considers the impact of significant wave height, wind speed, and the occurrence of hurricanes on construction schedule and cost. The model utilizes data obtained from the Department of Defense Master Environmental Library (MEL).

## Conclusion

In support of establishing the feasibility and cost of a MOB, a suite of modeling and simulation tools for evaluating the performance of the MOB in terms of overall operational performance, cargo transfer operations by sea and air, and constructability have been developed. These models will be used to conduct objective and consistent evaluations of different MOB concepts, and can be used by designers in any future MOB program to optimize designs and operations. With moderate enhancements, several of these models, and components of the rest, can provide direct benefit to the wider logistics community, especially in the simulation and evaluation of operations supporting seabased logistics.

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